Guidance for Design, Installation and Operation of In Situ Air Sparging Systems

PUB-RR-186 November, 2003

Purpose:
This is a guide to using in situ air sparging as a remediation technology. In situ air sparging is a process in which a gaseous medium (commonly air) is injected into groundwater through a system of wells. As the injected air rises to the water table, it can strip volatile organic compounds (VOCs) from groundwater and the capillary fringe. The process also oxygenates groundwater, enhancing the potential for biodegradation at sites with contaminants that degrade aerobically.

The DNR developed this guidance for environmental professionals who investigate contaminated sites and design remedial systems. Designing an in situ air sparging system is a multi-disciplinary process; the designer should have a working knowledge of geology, hydrogeology and basic engineering to design an effective system. The majority of this guidance is intended for smaller VOC contaminated sites; however, some of the guidance is appropriate for larger sites. Designers may need to deviate from the guidance in some circumstances because each site has unique contaminants, access constraints, size, hydrogeology, and other characteristics. If site-specific criteria or conditions require a cost-effective system design that differs from this guidance, it is the responsibility of the remediation system designer to propose an effective system to the DNR.

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Errata:
This document includes errata and additional information prepared in August, 1995.
The DNR rule cites and references to other DNR guidance in the document were also reviewed and found to be current, with the exception of the references to NR 112, which has been renumbered NR 812 and references to SW-157, "Guidance for Conducting Environmental Response Actions", which is no longer current guidance.

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Electronic version of:

GUIDANCE FOR DESIGN, INSTALLATION AND OPERATION
OF
IN SITU AIR SPARGING SYSTEMS

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Important notes to users of the guidance that was obtained in electronic format instead of hard copy format are as follows:

The hard copy version includes figures that are not available in electronic format.

This document is available in electronic format as a WordPerfect Version 5.1 document. The document uses superscripts, subscripts, underlines, italics, and mathematical characters that are unique to WordPerfect. The top of this page, the next page, the first table of contents page and the page with the introduction have WordPerfect commands for font, tab settings, margins, etc. In some cases, forced page breaks are used, in other places soft page breaks are used. A WordPerfect header command using small print is also used.

There are several mathematical formulas that will not print properly if a proportional font is used or if different tab settings are selected. Also, some of the mathematical formulas require the use of half line spacing.

For example:

$$s = \frac{2.3\ Q}{4\ \eth\ T}\ Log_{10}\ \left(\frac{2.25\ T\ t}{r^2\ S} \right)$$

If the above formula looks correct when it is printed out on your printer, your computer and printer are probably configured properly. If however the above formula looks incorrect, there may be other errors throughout the document.

For the above reasons, other software programs that are unable to translate from a WordPerfect 5.1 file may cause problems. In this case, the user may consider obtaining hard copies of this document instead.

This file of the document also includes errata and additional information through August 11, 1995.

There has been a great amount of research published since the original guidance was written. Much of the information here is intended to bring the guidance up to date.

Additional information, changes, clarification and errata to the *Guidance for Design, Installation and Operation of In Situ Air Sparging Systems* includes the following:

- <u>DNR Rules.</u> The guidance document was completed prior to the effective date of the NR 700 series of rules. There are many additional requirements within NR 724 for submittal contents that are not included in this document. Also, there may be other requirements in other chapters that affect an individual project.

- <u>Subsection 2.1. Air Flow Dynamics.</u> Recent research has demonstrated that the air flow passes through saturated soil in the form of channels, not as bubbles at almost all sites. Only a small percent of sites have an average grain size of 2.0 mm or larger, which is necessary for bubble flow (Ahlfeld, et. al., 1994). Since bubble flow is necessary for the formation of convection currents, the presence of convection currents is less likely to exist at any given site than previously thought. There have been a number of papers published recently that substantiate this (Ahlfeld, et. al., 1994, Johnson, et. al., 1993, and Wi, et. al. 1993, and Hinchee, 1994).

  Also, for this reason, Figure 2-1 should be discarded.

- <u>Subsection 2.1. Upwelling.</u> Further research has demonstrated that almost all upwelling is caused by displacement (channel flow) and very little by density affects (bubble flow). When air is injected, air displaces the water within the aquifer near the well screen as air channels are formed. The water then is driven upwards and laterally away from the zone surrounding the well screen. Once the air channels are formed and stable, the water table then returns to near static levels. After air injection ceases, the water flows back into the formerly air filled voids as the air rises to the water table.

- <u>Subsection 2.1. Diffusion and Rate Limitations.</u> Additional research has demonstrated that there is a diffusion limitation for contaminants to be volatilized into the air channels. The reason for diffusion limitations is that air channels typically are several inches to several feet apart from each other. Since the water in contact with the air channel is the only location where VOCs and oxygen are transferred out of and into ground water, the contaminants therefore must migrate several inches to several feet through molecular diffusion processes to reach the air channel for volatilization. Since the air channel diameter is typically quite small (approximately the size of the pore space between the soil particles), the surface area of the air and water interface of each air channel is extremely small, resulting in very slow mass exchange rates.

  The ground water at a distance from the air channel can be quite high in VOC content however the water at the air channel (air/water interface) will have reduced VOC content. Therefore, a concentration gradient often is created within the ground water regime, the magnitude of the gradient is in part dependant on the time that the air channel remains due to continuous operation.

  Cycling (or pulsing) the system repeatedly displaces and mixes the ground water, which reduces the magnitude of that concentration gradient, reducing the impact of diffusion limitations. For that reason, cycling air flow to each well is strongly recommended to help counteract diffusion limitations. When a system is operated continuously without cycling, the air channels are essentially permanent in location. When this occurs, the concentration gradient (and diffusion limitations) are greatest.

- Subsections 2.1 and 4.1. Groundwater Extraction Coupled with In Situ Air Sparging. The guidance indicated that groundwater extraction may be necessary to provide hydraulic containment of convection currents. As discussed above, convection currents are likely to exist only at a very small number of sites with an average grain size greater than 2 mm. Therefore combining in situ air sparging with ground water extraction is not necessary at most sites and is somewhat uneconomic.

- Subsection 2.2.3. New Recommendation for Minimum Permeability. Marley and Bruell (1995), Loden and Fan (1992) and Middleton and Hiller (1990) indicate that a hydraulic conductivity of at least $1 * 10^{-3}$ cm/sec is generally necessary to achieve an effective rate of air injection into an aquifer.

- Sections 3, 4 and 5. Monitoring Points and Methods. There is growing evidence that pilot tests and full scale operation often provide over optimistic results when those results are based only on ground water samples from monitoring wells. This is especially the case if dissolved oxygen in monitoring wells is the basis for estimating effectiveness.

  As discussed above, most air flow through saturated soils is in the form of channels and not bubbles. When air flow is in the form of channels, the vast majority of the air channels are through the most permeable zones. Even minor variations in permeability are sufficient to create preferred locations for air channel formation.

  Monitoring well filter packs typically are much more permeable than the native soils. This is especially the case when considering vertical permeability, the vertical permeability of filter packs is usually over an order of magnitude more permeable than the vertical permeability of the native soils because filter packs are nearly free of stratification. For this reason, air channels formed in the in situ air sparging process will preferentially intersect and flow through monitoring well filter packs.

  When the well screen is longer than a couple of feet, the air is also very likely to pass through the screen into the well itself. This is the reason that bubbling is often observed in monitoring wells at in situ air sparging sites.

  Therefore, the water in monitoring well filter packs and the wells themselves usually receive much more air flow than the rest of the aquifer, resulting in much more aggressive treatment by air stripping and oxygenation. Therefore, changes in chemistry in monitoring wells are generally not representative of the aquifer as a whole. For this reason, when the effectiveness of air sparging is measured by changes in ground water chemistry in conventional monitoring wells, the results are usually over optimistic. There are several options to choose from to procure more representative data, as follows:

  — The wells can be sampled after the system has been shut down for sufficient time to allow natural ground water migration to deliver ground water from several feet away from the well to the monitoring wells. The time interval is dependant on the estimated natural ground water velocity.

  — When purging monitoring wells prior to sampling, the purge volume can be greater. Since the purge volume must remove all of the "treated" water in and near the filter pack to draw in "untreated" aquifer water, the volume to purge can be considerable.

  — Small diameter driven probes may be used to procure ground water samples. These probes are likely to provide much more representative information on water chemistry, they have no filter pack with high permeability to promote air channel formation and the screen length is very short (Johnson, 1995).

If short screened driven probes are used for water sampling to evaluate progress during operation, the consultant should keep in mind that NR 726.05(3)(a)3. requires that NR 141 wells be used for sampling for evaluating the site for site closure. Samples from driven probes may be quite useful for evaluating progress during operation, however to use them for close out, a preapproval under NR 141.27 or a variance to NR 141 and/or NR 726 may be necessary.

- <u>Subsection 4.1 and 4.4. New Minimum Air Flow Rate Recommendation.</u> There is a growing amount of research that indicates that the ability of an in situ air sparging system to clean an aquifer is a function of the number of air channels that form within a given volume of soil (air channel density) (Wi, et. al., 1993). Also, that research has demonstrated that increasing the air flow rate can greatly increase air channel density, but not necessarily the zone of influence of the well. Therefore, it can be concluded that a significant amount of air flow per well is necessary to produce an air channel density that is capable of cleaning up high contamination levels. For this reason, a new recommendation of at least 5 scfm per well is used instead of the previous recommended minimum of 0.5 scfm. If the permeability is too low to allow 5 scfm, perhaps in situ air sparging is not the appropriate remedial method for the site. The minimum ratio of air extraction to air injection remains at 4 to 1.

  At sites with high contaminant levels and/or contaminants that have a very low Henry's Law Constant, professional judgement is necessary. Some of these sites may need much more than the 5 scfm minimum proposed here to be effective.

- <u>Subsection 4.3. Cycling.</u> The use of solenoid valves is discussed in the guidance, however only briefly. Subsequent research has demonstrated that the use of solenoid valves is much more useful than previously thought for several reasons:

  — Improved ground water mixing reduces the impact of diffusion limitations.

  — In situ air sparging primarily treats contaminants in the dissolved phase. Increased ground water mixing within the contaminated aquifer can increase the rate of contaminant desorption from aquifer soils. Increasing the desorption rate of residual phase contaminants speeds up the remediation.

  — Better control of the air volume that is injected into each well occurs when each well is activated for a fixed amount of time, reducing the potential for a well(s) to accept too much air with no or little air passing through another well(s) on a common manifold.

  For the above reasons, solenoid valves on every well are highly recommended. This allows each well to be cycled several times per day.

  If solenoid valves are used to cycle air flow into the wells, the "upwelling vs time" graph recommended in Subsection 3.3 can provide insight to an appropriate amount of time for each cycle. The injection time should be equal to or longer than the time interval to reach maximum upwelling during pilot testing, but significantly less than the time necessary for complete stabilization of the water table.

- <u>Subsection 4.4. New Recommendation for Maximum Air Pressure.</u> A number of systems have had failures due to high pressure. Some inadvertent aquifer fracturing has occurred and at least one site has experienced an annular seal failure on a well due to excessive pressure. The example calculations on page 26 in the guidance assumed 30 percent porosity with no safety factor. It is strongly recommended that calculations should assume 40 to 50 percent porosity and also include a 5 psig safety factor.

New example calculations are as follows:

Assumptions:
- soil particle density of 2.7,
- weight of water is 62.4 lbs/ft^3
- water table depth at 18 feet,
- sparging system screened interval from 30 to 35 feet,
- porosity of 40 percent or 0.4, and
- a safety factor of 5 psig is used.

To estimate the overlying pressure exerted by the weight of the soil column:

$$\text{Weight of soil} = 30\ ft * 2.7 * (1 - 0.4) * 62.4\ lbs/ft^3$$

$$= 3{,}033 \text{ pounds per } ft^2$$

$$\text{Weight of water} = (30 - 18)\ ft * 0.4 * 62.4\ lbs/ft^3$$

$$= 300 \text{ pounds per } ft^2$$

$$\text{Total} = 3{,}033 + 300 = 3{,}333\ lbs/ft^2$$

$$= 23.1 \text{ psig at 30 feet of depth (the top of screen).}$$

To estimate maximum pressure with safety factor:

$$23.1 - 5.0 = 18.1 \text{ maximum psig with safety factor.}$$

Instead of using a 5 psig safety factor, Marley and Bruell (1995) propose that the maximum pressure should be 60 to 80 percent of the calculated pressure exerted by the weight of the soil column above the top of screen. Using a 60 to 80 percent safety factor instead of a 5 psig safety factor is also acceptable. In this example, the maximum pressure would then be 13.9 to 18.5 psig *(0.6*23.1=13.9, 0.8*23.1=18.5)*.

Evaluation of N values on boring logs should also be used to qualitatively evaluate the appropriateness of porosity assumptions. Loose sand can have very high porosity relative to very dense sand, an assumption of 50 percent or more may be appropriate in loose sands.

This example is based on simplistic assumptions and designers should evaluate additional geotechnical information if it is available.

- <u>Subsection 4.5. New Recommendation for System Controls.</u> Due to potential air extraction equipment failures, there is the possibility that the sparging system could operate without the air extraction system. This could allow uncontrolled vapor migration in the subsurface, creating an unsafe condition. To further protect adjacent structures from a hazard of vapor migration, it is recommended that the blower on the soil venting system be continuously monitored by the control panel to assure that the venting system is continuing to place negative pressure on the soil within the air sparging regime. There are two recommended methods, as follows:

  - A sensor can be placed on a gas probe(s) near critical structures(s) to monitor for negative soil gas pressure. If the pressure in the gas probe rises to near atmospheric level, the sparging system should then be automatically shut down.

  - Or, a sensor can be placed on the stack of the venting system to monitor for positive pressure. If the pressure falls to near zero gauge pressure, that is an indication of low (or no) air flow from the air extraction system, in which case the sparging system should be automatically shut down.

Either method is likely to work well. The first is a better indication of subsurface conditions, however the second is a much lower cost option because no gas probe(s) need to be installed. Monitoring for vacuum at the manifold however is not a recommended option. If the top of the well screens become submerged (below water table), a high vacuum can be measured in the manifold when there is no air extraction from the soil. Professional judgement is necessary to determine the best mechanism to use in any given situation.

Professional judgement also is necessary to evaluate the importance of upgrading existing systems. In many cases this probably is not necessary due to low levels of VOCs in the subsurface after several months to years of operation. On systems that have only been recently installed, if there are high levels of VOCs remaining, that could pose a much greater hazard. Measurements of the lower explosive limit (LEL) in gas probes and/or water table wells at the site may provide useful data on the importance of upgrading existing systems.

- <u>Subsection 4.7. Additional Criteria for Design Report Submittal.</u> Due to the number of systems that have been proposed and/or installed in soil that is inappropriate for in situ air sparging, in addition to the recommended list of contents for a design report, the discussion section should also include a description of SUFFICIENT DETAIL on why in situ air sparging is appropriate for the site if any of the following conditions exist:

  — The hydraulic conductivity is less than $1 * 10^{-3}$ cm/sec.

  — The boring logs and/or cross sections indicate a fine grained saturated layer between the well screen and the static water level.

  — The boring logs are incomplete (see list on pages 11 and 13 in the guidance) for a list of items to be included in boring logs.

  — If the average air flow rate per well cannot be maintained at 5 scfm or more in each well.

  — If the well spacing is farther apart than 30 feet.

- <u>Section 6.0 References.</u> Additional references that should be added include the following:

Ahlfeld, D.P., Dahmani, A., and Ji, W. 1994. A Conceptual Model of Field Behavior of Air Sparging and Its Implications for Application. *Groundwater Monitoring and Remediation.* Fall 1994. Pages 132 to 139.

Hinchee, R.E., editor. 1994. *Air Sparging for Site Remediation* Lewis Publishers, Ann Arbor, Michigan.

Johnson, R.L., Johnson, P.C., McWhorter, R.E., and Goodman, I. 1993. An Overview of In Situ Air Sparging. *Groundwater Monitoring and Remediation.* Fall 1993. Pages 127 to 135.

Johnson, R.L. 1995. Presentation to the Third International Symposium on In Situ and On Site Bioreclaimation. San Diego, CA. April 1995.

Loden, M.E. and Fan, C.Y. 1992. Air Sparging Technology Evaluation. *Proceedings of the National Conference on the Control of Hazardous*

Materials. Hazardous Material Control Research Institute. Pages 328 to 334.

Marley, M.C. and Bruell, C.J. 1995. *In Situ Air Sparging: Evaluation of Petroleum Industry Sites and Considerations for Applicability, Design and Operation.* API Publication 4609, American Petroleum Institute.

Middleton, A.C. and Hiller, D. 1990. In Situ Aeration of Ground Water: A Technology Overview. *Proceedings of the 1990 Environment Canada Montreal Conference.*

Wi, J., Dahmani, A., Ahlfeld, D.P., Lin, J.D., and Hill, E.H. 1993. Laboratory Study of Air Sparging: Air Flow Visualization. *Groundwater Monitoring and Remediation.* Fall 1993. Pages 115 to 126.

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Gale K. Billings, C.P.G. - Billings and Associates, Inc.
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This document may not represent the views of all reviewers. The Department of Natural Resources extends thanks to reviewers for the donation of their time and invaluable input.

Acronyms

CFM	Cubic feet per minute
CPVC	Chlorinated polyvinyl chloride. Material commonly used for pipe.
DNR	Wisconsin Department of Natural Resources.
ERP	Environmental Repair Program of the DNR.
ERR	Emergency and Remedial Response Section of the DNR Bureau of Solid and Hazardous Waste Management which includes ERP, Superfund, LUST, Spills and Abandoned Containers.
LUST	Leaking Underground Storage Tank Program of the DNR.
mm	Millimeters.
MTBE	Methyl tertiary butyl ether.
NR	Wisconsin Administrative Code that is enacted by the DNR.
ppb	Parts per billion
ppm	Parts per million
psig	Pounds per square inch gage pressure.
PVC	Polyvinyl chloride. Material commonly used for pipe, well casing, and well screens.
QA	Quality assurance
QC	Quality control
scfm	Standard cubic feet per minute.
TPH	Total petroleum hydrocarbons. As used in this guidance, TPH means analytical tests such as GRO, DRO, and TRPH.
VOC	Volatile organic compound.

1.0 Introduction.

This guidance document is intended to aid environmental professionals in designing in situ air sparging systems to remediate contaminated groundwater. It also provides information to Department of Natural Resources (DNR) staff for efficient and consistent oversight and review.

This document should be used with the existing DNR *Guidance for Conducting Environmental Response Actions*, specifically Chapter 7 (Site Investigation) and when available, Chapter 8 (Remedy Selection).

1.1 Purpose.

This is a guide to using in situ air sparging as a remediation technology. In situ air sparging is a process in which a gaseous medium (commonly air) is injected into groundwater through a system of wells. As the injected air rises to the water table, it can strip volatile organic compounds (VOCs) from groundwater and the capillary fringe. The process also oxygenates groundwater, enhancing the potential for biodegradation at sites with contaminants that degrade aerobically.

The DNR developed this guidance for environmental professionals who investigate contaminated sites and design remedial systems. Designing an in situ air sparging system is a multi-disciplinary process; the designer should have a working knowledge of geology, hydrogeology and basic engineering to design an effective system.

The majority of this guidance is intended for smaller VOC contaminated sites; however, some of the guidance is appropriate for larger sites. Designers may need to deviate from the guidance in some circumstances because each site has unique contaminants, access constraints, size, hydrogeology, and other characteristics.

If site-specific criteria or conditions require a cost-effective system design that differs from this guidance, it is the responsibility of the remediation system designer to propose an effective system to the DNR.

1.2 Applicability of In Situ Air Sparging.

In situ air sparging is generally limited to the remediation of contaminated groundwater in shallow portions of unconfined aquifers. Marley (1991 and 1992), Ardito (1990) and Brown (1992) discuss site-specific applications of this technology.

Generally, air sparging works best in shallow water table aquifers; however, air sparging may also be an appropriate choice for deep aquifer contamination in rare cases.

Air sparging is not appropriate for sites with groundwater contaminants that cannot be remediated by air stripping or degraded aerobically. For example, air sparging may not be appropriate for some LUST sites with very high concentrations of methyl tertiary butyl ether (MTBE).

In some situations, other remediation technologies may be more effective than in situ air sparging. Johnson, et al. (1992) demonstrated in a large-scale laboratory demonstration project that using groundwater extraction to lower the water table for soil venting is more effective than in situ air sparging. There are sites where the cost of pumping to lower the water table is impractical; in these situations, in situ air sparging may be an appropriate choice.

In most cases, air sparging is used in conjunction with a soil venting system (See *Guidance on Design, Installation and Operation of Soil Venting Systems*). If soil vapor extraction is not used, the system must meet the criteria discussed in Subsection 1.3.1 of this guidance. An air sparging system may also be used in conjunction with a conventional groundwater pump and treat system (See *Guidance on Design, Installation and Operation of Groundwater Extraction and Product Recovery Systems*). In situ air sparging has been used to remediate groundwater at some Leaking Underground Storage

Tank (LUST) sites without using groundwater extraction.

Air sparging should only be used at sites with appropriate geologic conditions. Any layers of fine-grained materials or any other geologic heterogeneities that may limit vertical migration of air to the water table surface will limit the ability of air sparging to work efficiently.

The following are examples of situations where this guidance may not be completely appropriate:

- A site with 10 air sparging wells is likely to need continuous split spoon sampling in the majority of the wells for verification that the geologic characterization is accurate; but a site with more than 100 wells clearly does not need to have the majority of the wells sampled.

- A very small site with a highly permeable (>1 E-2 cm/sec), relatively isotropic aquifer that will use air emission controls on the soil venting system may not need the level of detail proposed for pilot testing. At such a site, air flow is restricted primarily by the pressure necessary to depress the water column within the sparging wells. In this case, pressure requirements of the system may be estimated based on static water levels. An additional estimate of the pressure requirements to counteract pipe friction, change in head due to upwelling, and the pressure necessary for air entry into the aquifer is also needed. Since an air emission control system is proposed, pilot testing is not necessary to quantify an emission estimate.

- Wells smaller than those recommended by the guidance may be used at a site with a very large system that has sufficient groundwater monitoring wells. At these sites, the cost of more than 50 wells – all 2 inches in diameter with threaded access caps on the wellheads – may be excessive.

Although this guidance specifically refers to injecting air into groundwater, there may be times when injecting ozone, oxygen, ammonia, nitrogen, or possibly other gaseous substances are appropriate. The use of substances other than air, oxygen or ozone requires approvals from the DNR Water Supply program and should be justified in a workplan.

1.3 Permitting and Other Regulatory Requirements.

Refer to Table 1-1 for more information on permitting and related guidance documents.

Table 1-1

Guidance Documents Related to In Situ Air Sparging

Topic	Pertinent Rules	Guidance Documents[1]	Agency Contact	Reference Section
Coupling System with a Soil Venting System	None	None	DNR District ERR Staff	Subsection 1.3.1
Air Emissions	NR 406, 419 and 445	None	DNR Air Management Staff	Subsection 1.3.3
Drilling, Well Construction, and Abandonment	NR 141	None	DNR District ERR Staff	Subsections 1.3.1 and 4.2
Well Labeling and Color Coding	ILHR 10	None	DILHR	Subsection 1.3.4
Injection Wells	NR 112	August 14, 1991 Memo[2]	Injection Well Coordinator in Water Supply	Subsection 1.3.2 and 4.5
Investigative Wastes	Various DNR Rules	January 14, 1993 Memo[3]	DNR District ERR Section	Subsection 1.3.1
Electrical Safety	Various DILHR Rules	DILHR UST/AST Program Letter 10; May 25, 1993[4]	DILHR Staff and/or Local Building Inspectors	Subsections 1.3.4 and 4.4

Notes:
(1) Guidance Documents refers to guidance documents other than this document.
(2) Guidance attached as Attachment 1.
(3) Guidance titled *General Interim Guidelines for the Management of Investigative Waste.*
(4) Guidance titled *Design Criteria for Process Equipment Buildings Associated with Environmental Remediation of UST/AST Sites*, included as Attachment Two to the *Guidance on Design, Installation and Operation of Groundwater Extraction and Product Recovery Systems.*

1.3.1 LUST, ERP, and Superfund Program Requirements.

Submittal Contents. Recommended LUST, ERP and Superfund program submittal contents are listed in Subsections 3.3, 4.7, 5.3, and 5.4.

Soil Venting Systems and Vapor Phase Transport. A soil venting system used in conjunction with an air sparging system is necessary to limit/prevent vapor phase migration when ANY of the following conditions exist at a site:

- The air sparging wells are in an area that has contaminated, unsaturated soil. It is impossible to estimate the emissions from an air sparging system that is not used in conjunction with a vapor extraction system in contaminated soil. Soil samples from soil borings should be collected to confirm that the unsaturated soil is uncontaminated if a soil venting system is not planned.

- Any buildings or other structures within 100 feet of any air sparging well that may accumulate vapors.

- More than 50 percent of the ground surface is paved within 50 feet of any air sparging well. Pavement may cause lateral vapor phase migration of VOCs.

- Clay or silt layers are present in the unsaturated zone that may cause lateral vapor phase migration of the VOCs.

- There is a potential for any free floating product at the site. Upwelling could spread the free product to "clean" areas.

- There is evidence that air emissions could exceed air standards.

- On a site-specific basis due to other factors, the DNR may require a soil venting system to be used in conjunction with an air sparging system.

When a soil venting system is installed, the soil venting system should extract at least four times as much air as injected by the air sparging system, unless other means are used to demonstrate that all injected air is captured and there is no vapor phase migration. The soil venting system's zone of influence should cover the entire area covered by the air sparging wells to assure that all emissions are captured and quantified. If any structures are located near the sparging wells, gas probes should be used to assess subsurface pressure and vapors (See Subsection 5.2).

If a soil venting system is not proposed, a minimum of two gas probes should be used to evaluate the presence of subsurface vapors and pressure. Water table observation wells that are located within the system's zone of influence may be used as substitutes for gas probes.

Wis. Admin. Code NR 141. Well design details are site specific. Because some wells at a site may be used for groundwater sampling, they must be developed to NR 141 standards. Consultants should submit boring logs and well-construction diagrams after well installation, in accordance with NR 141. If the wells are used for collecting groundwater samples or preparing a piezometric surface map, they must be surveyed to NR 141 requirements. Well abandonment procedures in NR 141 are applicable.

Investigative Wastes. Drill cuttings should be handled in accordance with DNR guidance on investigative wastes.

1.3.2 Bureau of Water Supply.

Injection Well Issues. Because air sparging uses injection wells, it is regulated by the DNR Bureau of Water Supply under Section NR 112.05 of the Wis. Admin. Code. The LUST program has the authority to approve air sparging systems on behalf of the Bureau of Water Supply if air, oxygen or ozone — and no other substances that may adversely impact water quality —

are injected into the groundwater (See Attachment 1). The Bureau of Water Supply must approve projects if nitrogen or other gases are injected into groundwater, or if compressors that are not oil-less are used. A separate approval from the Bureau of Water Supply may also be needed for ERP and Superfund program sites.

1.3.3 Bureau of Air Management.

Wis. Admin. Codes 406, 445, and 419. The DNR Bureau of Air Management regulates air emissions from remediation sites. All air sparging systems need preapproval from the Bureau of Air Management prior to installation. If a soil venting system is also used at a site, the emissions from an air sparging system are drawn into the soil venting system which allows the operator to sample and quantify the emissions.

See Attachment 1 of the *Guidance on Design, Installation and Operation of Soil Venting Systems* for air emission limits at LUST sites. Chapters NR 419 and 445 contain a complete listing of compound-specific limits for other sites. The lower of the total VOC limits in NR 419.07 and the limits for individual compounds in NR 445 apply to non-LUST sites.

If a soil venting system is not proposed for a site, designers should estimate the air emission rate for contaminants that will be released into the atmosphere through the ground surface.

1.3.4 Department of Industry, Labor and Human Relations.

ILHR 10. Designers must follow the Department of Industry, Labor and Human Relations' (DILHR) rules related to flammable and combustible liquids, electrical safety and building safety. See Attachment 2 to the *Guidance for Design, Installation and Operation of Groundwater Extraction and Product Recovery Systems* for a discussion of DILHR's rules.

ILHR 10.41 covers color coding for flush mount well covers of groundwater monitoring wells and vapor wells. For purposes of ILHR 10, an air sparging well is considered a groundwater well.

2.0 Technical Considerations and Site Characterization.

2.1 Theory.

Injecting compressed air into an aquifer accomplishes two goals:

- Air Stripping. As the air rises to the surface of the water table, VOCs are stripped from the contaminated groundwater.

- Oxygenation. The groundwater is oxygenated, which enhances biodegradation of aerobically degradable organic compounds.

Pumping air into the aquifer causes the following to occur:

- Vapor Phase Migration. The injected air creates a slight positive pressure in the unsaturated zone near the air sparging wells. If no soil venting system is used, vapor phase migration of VOCs may occur. If a soil venting system is used, it should be designed to capture the vapors.

- Changes in Aquifer Characteristics. The effective porosity to water flow is reduced when there is a mixture of liquid and gas phases in the aquifer, reducing the hydraulic conductivity.

Air sparging technology is fairly new and the dynamics are not yet well understood. Other potential effects of air sparging that have not been fully evaluated through research include the following:

- Air Flow Dynamics. It is not yet clear if the air moves through the aquifer as a large number of very small bubbles, or if the air flows through preferred (finger-like) flow channels in natural soils. For a given volume of air, channeling reduces the air contact surface area to groundwater and aquifer material, which reduces the mass transfer of VOCs and oxygen. The distribution of the channels, and the subsequent mass transfer limitations of VOCs and oxygen, dominate the effectiveness of the process. Marley (1992) briefly discusses this effect.

  Ahlfeld (1993) indicates that the density and viscosity differences between air and water and the capillary resistance produced by the surface tension at the air/water interface within the soil pores govern whether or not bubbles or channels form. Various sizes of glass beads were used in laboratory experiments to evaluate the air flow dynamics. In the lab, it was visually determined that a grain size of 0.75 millimeters (mm) or less resulted in channelized flow, however, grain sizes greater than 4 mm resulted in bubble flow. In between 0.75 and 4 mm grain size, there was a transition between bubbles and channeling. Ahlfeld (1993) further indicates that very small heterogeneities can control the air flow dynamics in a medium that otherwise appears to be homogenous.

  If there are stratified soils present at a site, the air is likely to flow through high-permeable strata in an unpredictable manner. Ahlfeld (1993) suggests that strata of differing permeabilities produces air flow patterns that are strongly controlled by the contrast in permeability, the geometry, and the size of the strata. Ahlfeld (1993) further proposes that the injected air will not reach soil immediately above a low permeability zone because the low permeability soil will be a barrier to air flow. In this case, that soil is not readily remediated by the system.

  If there are stratified soils, it is also possible that high levels of contaminants could be forced into clean areas outside the soil venting system's zone of influence.

- Convection Currents. Convection currents form and circulate the groundwater near the wells (Wehrle, 1990). The convection currents are formed because the bulk density of the air bubble and water mixture near the well(s) is less dense than the groundwater that is farther away from the well(s). This creates groundwater upwelling near the air sparging well(s), which continuously provides a mechanism for circulating water from other areas to the area of the air sparging well(s). See Figure 2-1.

It is likely that groundwater convection currents are strongest when air flow is in the form of small bubbles. In this case, the gas phase and liquid phase move through similar flow pathways. If the air flows in channels, the air and liquid phase are likely to take different flow pathways which reduces or eliminates the formation of convection currents.

The convection currents are likely to be strongest when the site's conditions are nearly isotropic. Stratification will reduce the ability of the system to create convection currents. Significant stratification may cause air pockets to develop in the aquifer and may completely prevent the formation of convection currents.

The convection currents may also cause significant lateral transport of the groundwater, possibly forcing contaminated groundwater into previously uncontaminated locations. In some situations — such as submerged plumes or small, highly concentrated plumes — the migration of contaminants away from the sparging points into "clean" areas is a significant concern. Groundwater extraction may be necessary in some situations to provide hydraulic containment of the convection currents.

- <u>Upwelling.</u> Water table upwelling occurs due to the added pressure and volume of air that is applied to the saturated zone. Current literature indicates that upwelling is usually less than a foot. The amount of upwelling is dependant on injection pressure and soil properties.

  Some practitioners propose that upwelling remains as long as air is injected, however, other practitioners propose that initial upwelling is transient and dissipates. Current theories include the following proposals:

  - Air transport will probably be in the form of bubbles at sites where upwelling remains during air injection. In this case, the upwelling is due to the non-equilibrium

condition caused by lighter bulk density of the air-water mixture near the air injection point.

- Air transport will probably be in the form of channels if upwelling is transient and dissipates within a day (or less) after air injection is started. In this case, upwelling is initially caused by the formation of air channels as the air displaces the groundwater. With time, the water level will drop to static levels as the water table attempts to reach an equilibrium level.

Martinson and Linck (1993) present data from multiple monitoring wells at a specific site (See Figure 8 in Martinson and Linck's paper). At this example site, approximately 50 percent of the initial upwelling dissipated within one hour after startup, approximately 75 percent of the initial upwelling dissipated in two hours, and approximately 90 to 95 percent of the initial upwelling dissipated in a day. After a number of days of system operation approximately 5 percent of the initial upwelling remained. In this example, most of the upwelling effects are probably caused by initial air displacement effects as air channels form. Because some upwelling is permanent (remains as long as the system is operating), it is also likely that some of the upwelling is caused by density effects. Because upwelling in this case is neither completely permanent or transient, it is likely that both air channeling and convection currents exist at this particular site.

- <u>Aquifer Clogging and Redox Conditions.</u> Iron at high concentrations may precipitate into the aquifer, reducing porosity and permeability. Other metals may also precipitate within the aquifer, due to the change in redox conditions. There is no good guideline for a maximum iron concentration; it is likely that dissolved iron concentrations higher than 10 mg/L could cause precipitation problems. However, this guideline may change with more project experience.

  Increasing the dissolved oxygen level in the groundwater may mobilize some metals, including cadmium. Using geochemical models such as MINTEQA2, may help designers estimate the potential for precipitating or dissolving metals.

  Gas phase clogging may occur in some geologic situations because air pockets can be trapped in the interstitial void spaces within the aquifer. This is most likely to occur in stratified soils where silt and clay layers trap the gas phase.

  Sites that are contaminated with aerobically degradable compounds generally have low-dissolved oxygen in the groundwater because the oxygen has been used up by biological activity. Therefore, oxygen in the trapped air pockets can dissolve into the groundwater. Inert nitrogen is left (which does not readily dissolve), reducing the effective porosity to groundwater flow and lowering effective water permeability.

  Biofouling may occur if a biomass forms in the void spaces within the aquifer.

  If oxygen is used instead of (or as a supplement to) air injection, significant redox changes will occur which increases the risk of aquifer clogging relative to air injection.

- <u>Temperature Requirements.</u> Both volatilization and biodegradation are enhanced with higher temperatures. It has not been determined if adding heat to the injected air is cost-effective. Some heat is added to the air because the air is compressed (ideal gas laws).

Air that is below the natural groundwater temperature should not be injected. Note: Although heat is added in the compression process, the temperature may drop below freezing in winter in long piping systems exposed to subfreezing conditions.

- Potential Changes in Secondary Permeability. Excessive pressures may cause irreversible aquifer fracturing and increased flow through secondary porosity. While creating additional channels through the aquifer may increase the rate that air flows through the aquifer, it also creates channeling of air which reduces the VOC and oxygen mass transfer rate.

  Generally, advective flow through primary porosity is preferred to flow through secondary porosity because secondary porosity flow results in diffusion-limited contaminant extraction. There may be situations where pneumatic fracturing or other high pressure techniques are preferable. However, because these changes are irreversible, designers should include a detailed justification in a workplan if high pressures are proposed. See subsection 4.4 for an example maximum pressure calculation.

Air sparging may remediate the smeared zone much faster than soil venting and groundwater extraction systems when it is used in the source area of a site with nearly isotropic and high-permeable conditions. This occurs because the air moves perpendicular to the zone of contamination — and not parallel to it — and all of the air passes through the zone(s) of highest contamination.

In soil venting systems, only a very small percentage of the total air flow passes through the capillary fringe, which is often the highest contamination zone. Soil venting combined with groundwater extraction may be more effective in moderate to low-permeable, heterogeneous soil because the mass transfer of oxygen and VOCs is limited when air channeling occurs.

2.2 Site Characterization.

There are a number of characteristics that designers should assess at a site. A brief list of characteristics and their significance are highlighted below.

2.2.1 Contaminant Characterization.

Chemistry. Air sparging is an inappropriate remediation technology if some or all of the contaminants are not aerobically degradable, or are not removed by air stripping. Nyer (1985) contains an excellent discussion of air stripping. A sample(s) of groundwater should be analyzed for all regulated compounds that may be present at the site to assess in situ treatability.

Free Product. If there is any measurable floating product (measurable thickness greater than a film) within the sparging zone, the free product should be removed using groundwater extraction and product recovery prior to operating an air sparging system. Otherwise, groundwater upwelling near the sparging wells may cause free product to migrate to formerly uncontaminated areas. The DNR will only allow sparging within a zone of free product in rare situations, and only if there is a groundwater extraction and product recovery system also in use.

If an air sparging system is proposed at a site with a small volume of free product (too small to recover by pumping), the system designer should describe the measures that will be taken to prevent free product migration away from the sparging system in the work plan. In this case, a soil venting system is also necessary because of the high quantity of contaminants. It is also likely that air emission control and permitting will be needed on the soil venting system.

Oxygen Levels. When the contaminants at the site are aerobically biodegradable, testing for dissolved oxygen should be conducted to determine a baseline of dissolved oxygen levels prior the air sparging system start-up. The DNR recommends that consultants conduct at least two rounds of dissolved oxygen sampling in all monitoring and possibly some sparging wells at the site.

2.2.2 Geological Characterization.

Geologic Characterization. Air sparging depends on the ability of injected air to strip VOCs from the groundwater and rise to the water table where it exits the saturated zone. ANY LAYERS OF FINE-GRAINED MATERIALS OR ANY OTHER GEOLOGIC HETEROGENEITIES THAT MAY LIMIT VERTICAL MIGRATION OF AIR TO THE WATER TABLE SURFACE WILL ADVERSELY AFFECT THE ABILITY OF AIR SPARGING TO WORK EFFICIENTLY (See Figure 2-2).

> Note: In Figure 2-2, the air flow patterns in the saturated zone are assumed to curve outward from the well in the isotropic example because of groundwater convection patterns shown in Figure 2-1.

A deep boring(s) is needed prior to designing an air sparging system to assess the geologic conditions in the depth interval between the water table and the base of the sparging well screen. This boring could be drilled during the site investigation.

A hydrogeologist as defined in NR 500.03 (64) or NR 600.03 (98) should classify the borings in detail. A soil description should include the following:

- Approximate percentages of major and minor grain size constituents,

  > Note: Terms such as "and," "some," "little," "trace," etc. are acceptable if defined in percentages they represent.

- Color and Munsell color,

- Geologic origin,
- Description of moisture content (dry, moist, wet),
- Any visual presence of secondary permeability,
- Voids or layering,
- Pertinent field observations such as odor,
- A description of any evidence of product smearing. Since depth of smearing is evidence of past aquifer water level variations, note the depths carefully.

Sparging system designs for sites with any stratification should include a detailed description of how the design is tailored to the site's geological conditions.

Average Grain Size. The soil below the water table should be characterized for grain size by sieve analysis for filter pack and screen slot size design (See Subsections 4.2.2 and 4.2.4).

2.2.3 Hydrogeological Characterization.

Primary Permeability. High horizontal permeability is necessary to allow air to be injected into the aquifer at an effective rate. The vertical permeability must be high enough to allow the air to rise through the aquifer and exit at the water table. Subsection 4.4 discusses air flow rate per sparging point in more detail.

Secondary Permeability. If a significant portion of the air flows through fractures or channels, then only some of the contaminated soil or water will be in contact with the air stream. In this case, the effectiveness of air sparging is reduced and it will take longer to clean up the contamination. This is likely to occur in glacial till and fractured consolidated deposits, and to a lesser degree in other soil types.

Depth to the Water Table and Time Varying Conditions. Designers should estimate the depth to water table under all seasonal conditions. This information is necessary to design wells and to select air compressors. Subsections 4.2.2, 4.2.4, and 4.4 discuss the importance of depth to the water table.

Groundwater Migration. The natural rate of groundwater migration past the air sparging wells is a very important parameter. Air sparging is a groundwater remediation technology, thus the groundwater regime should be accurately understood. Designers should conduct aquifer testing on a number of monitoring wells at the site. The wells used for air sparging may only be used for bail down or slug tests if the filter pack is sufficiently coarse. Because the recommended filter pack size for air sparging wells is equal to or finer than the native soils (See subsection 4.2.2), bail down/slug test results from sparging wells may exhibit artificially low results. Bail down/slug tests and step drawdown tests are discussed in Section 3.0 of *Guidance on Design, Installation and Operation of Groundwater Extraction and Product Recovery Systems*.

3.0 Treatability or Pilot Testing.

3.1 Laboratory Treatability Tests.

There are no applicable laboratory treatability tests for air sparging. If biodegradation is a key part of the remediation process at a site, degradability tests should be used to assess the need for supplementary nutrients or estimating the rate of decay. Most LUST sites do not warrant any laboratory biodegradation studies because most petroleum-based hydrocarbons are easily degraded aerobically.

3.2 Pilot Tests.

A pilot test is conducted for two purposes: engineering design and estimating emissions from a soil venting system (if used).

The equipment for an air sparging pilot test generally includes the following:

- Air Compressor. The air compressor can be any type of air compressor listed in Subsection 4.4. The compressor should be large enough to inject sufficient pressure and flow to at least one well and possibly multiple wells simultaneously. An appropriate range for minimum capacity is approximately 3 to 10 scfm and 6 to 20 psig per well. Designers should avoid using high-pressure compressors that may pneumatically fracture the aquifer.

- Manual Pressure Relief Valve. A manual pressure relief valve should be installed at the blower outlet to manually relieve air pressure to control pressure and flow rate. Using a throttle valve may be used instead of a manual pressure relief valve on compressors that are equipped with a receiver and automatic high-pressure shut-off switch.

- Pressure Gauge. The pressure gauge may be calibrated in inches of water column or in psig. It should be installed on the pipe between the air compressor and the air sparging well. Two digits of accuracy is recommended.

- Flow Meter. The flow meter measures the rate of air injection. It may be a heated wire anemometer or a rotameter; other devices are also acceptable. In general, pitot tubes do not provide accurate quantification of the air flow rate below an air velocity of 1,000 feet per minute. If designers use a pitot tube, they should install it on a pipe with a small enough diameter that provides sufficient air velocity for accurate results.

  Some flow meters may not provide accurate quantification of air flow when the air is compressed and heated (by compression); correction factors may be needed. Designers should consider pressure and temperature when evaluating the ability of the air flow meter to provide accurate results prior to use. Since the air is compressed, the flow rate should be corrected to standard temperature/pressure conditions (scfm, not cfm). Two digits of accuracy is recommended.

- Thermometer. The thermometer verifies that the additional heat from compressing the air does not damage the test equipment or well. If the temperature rises above 140 degrees fahrenheit, PVC may become too weak to hold the pressure. Temperature measurements may also be necessary for a correction factor to the flow meter measurements.

- Air Sparging Well(s). See Subsection 4.2 for a discussion of well design. The air sparging well(s) that are tested should be in an area of high groundwater contamination to provide a realistic estimate of emissions from the soil venting system.

If the well(s) tested are not in the highest areas of contamination, designers should estimate and use a correction factor based on groundwater sample results when estimating emissions that occur at start-up of the full-scale system.

- Automatic Pressure Relief Valve (Optional). An automatic pressure relief valve may be installed along with the manual pressure relief valve to assure that improper use of the manual valve does not inadvertently over-pressurize the system. If the system is over-pressurized, test equipment may become damaged and/or the aquifer could become pneumatically fractured. See Subsection 4.4 for a discussion of maximum pressure.

Pilot tests provide design data for full-scale implementation. The quality of the data for that purpose varies from site to site. Design data examples include the following:

- Test results from a simple site with wells installed less than 15 feet below the water table in highly permeable isotropic conditions are likely to provide excellent design data that is otherwise unobtainable.
- Data that is obtained at a site with relatively impermeable soils (<1 E-4 cm/sec) is likely to have air flow channeling. When high air pressures are necessary at sites with low-permeable soil, it is likely that each well at a site will behave differently. In these situations, a pilot test from a single well or only a few wells at the site may not represent the whole site. In these situations, after system start-up, it may be necessary to fine-tune the system to achieve a sufficient flow rate in every well.

To conduct a pilot test, system operators should increase air pressure slowly with the manual pressure relief valve. Pressure and flow readings should be taken at four (or more) different times at each valve setting to evaluate whether or not the pressure and flow rates have stabilized. Operators should take measurements using at least three different valve settings. In all cases, excessive pressures should not be used. See Subsection 4.4 for example calculations for determining maximum pressure. Stabilized pressure and flow data should be plotted on a graph that indicates the flow and pressure requirements for the well.

Note: Designers should not use early data if it does not correlate consistently with later data because early data may not have been from stabilized readings.

If designers install or anticipate installing a soil venting system, they should conduct both a pilot test for air sparging and soil venting to estimate emissions upon start-up of a full-scale combined system. Designers should conduct the soil venting pilot test for a minimum of one hour (preferably more) prior to air sparging to establish a baseline of vapor extraction capability and emissions without sparging. The system should then be operated for a minimum of three hours (preferably much longer) with the air sparging well or air sparging system activated.

Using the baseline level of air emissions (under air extraction only) and a stabilized emission rate with air injection, designers should calculate contaminant extraction levels that are attributable to sparging on a contaminant mass-per-air-volume basis at start-up.

Example: To estimate the emissions upon startup, use pilot test data.

Assumptions:

— All injected air is withdrawn by the air extraction system under stabilized conditions.
— 1 E-4 pounds of contaminants per cubic foot of air are

extracted under vapor extraction at 65 scfm without air injection.

- 5 E-4 pounds of contaminants per cubic foot of air are extracted at 65 scfm extraction rate and 5 scfm injection rate.
- The air sparging well is located in the most heavily contaminated part of the plume (if it is not, apply a correction factor based on groundwater sample results).

Vapor extraction (extraction only) baseline emissions.

*1 E-4 lbs/ft^3 * 65 scfm * 60 min/hr = 0.39 lbs/hr extraction rate.*

Emissions from vapor extraction and sparging (extraction and injection).

*5 E-4 lbs/ft^3 * 65 scfm * 60 min/hr = 1.95 lbs/hr extraction rate.*

1.95 lbs/hr - 0.39 lbs/hr = 1.56 lbs/hr increase attributed to air injection.

$$\frac{1.56 \text{ lbs/hr}}{5 \text{ scfm}} = 0.3 \text{ lbs/hr increase per scfm of injected air}$$

Note: Due to the unpredictable nature of air flow patterns and site-specific heterogeneities, the pounds per hour increase per scfm may be no more accurate than an order of magnitude. However, because better data is not available, it should be calculated and used for emission estimates.

If site conditions are conducive to estimating a zone of influence (described further in Subsection 4.1), designers should evaluate the zone of influence during the pilot test. It is unlikely that a single day test will provide accurate determination of the zone of influence, but the following qualitative data may be obtainable:

- Measuring upwelling in wells at the site. If upwelling is measured, periodic measurements should be taken in multiple monitoring wells to evaluate upwelling effects over time. Plotting a graph with upwelling effects over time may provide information on whether or not convection currents are likely to exist under active air sparging at the site.

- Measuring subsurface gas phase contaminant concentration changes in gas probes or water table wells.

If a soil venting system is not used during the test, changes in subsurface gas concentrations in temporary soil gas probes or water table observation wells may provide excellent zone of influence data. Because the measurable effects of a short-term test are dependant on the rapid transport of air through the aquifer and unsaturated zone, short-term tests may be unreliable at relatively impermeable sites. However, short-term tests may provide good quality data at high-permeable sites.

3.3 Pilot Test Reporting.

The reporting of a pilot test may be a separate report, combined with an investigation report, or included with the design report. Designers should include the following information in a pilot test report:

<u>Discussion.</u>

- General discussion describing the test and a discussion of the hydrogeological conditions at the site.

- Design of the sparging wells. List the screen length and diameter, slot size, depths and specification of the filter pack and seals, bore hole diameter, and the drilling method.

- A discussion of the air flow rates that were injected and extracted during the test and how the contaminant concentrations in the soil venting system (if installed) changed with differing air injection rates. Also include the ratio of extracted to injected air flow rates.

- If a zone of influence is estimated, discuss how the estimate was determined and provide a discussion of the field data that was used to make the estimate.

- Include conclusions reached for design (See Section 4), well placement and spacing, number of wells, pressure and air flow requirements for the air compressor, and any other pertinent details.

- Any other observations.

<u>Figures.</u>

- A graph indicating the pressure and air flow characteristics of the air sparging well(s) that was tested.

- If upwelling in monitoring wells is measured, the designer should include a graph indicating upwelling (y axis) versus time (x axis). Data from multiple wells can be included in a single graph.

- Geologic cross section(s).

- A map of the site drawn to scale, including:

  - locations of existing sparging wells,

  - locations of existing air extraction wells, if a soil venting system is used,

  - suspected and/or known source location(s) (if differing contaminant types are present at a site, identify the contaminant type at each source location),

  - zone of soil contamination,

  - zone of groundwater contamination,

  - scale, north arrow, title block, site name, and key or legend,

  - any other pertinent site information.

- A water table map for the day of the pilot test.

- An iso-concentration map with groundwater dissolved oxygen levels (if the contaminants are aerobically degradable);

<u>Tables.</u>

- Water levels/elevations and dates of measurements in monitoring wells.

- Field data, including times of readings, air flow rates, injected air temperature, and injected air pressure.

<u>Appendices.</u>

- Complete discussion of field procedures for the test.

- Boring log and construction diagram for sparging well(s).
- Calculations determining the hydraulic conductivity and natural groundwater migration rate.
- Laboratory reports, if applicable.

In addition, designers should include the information listed in Section 3.0 of the *Guidance on Design, Installation and Operation of Soil Venting Systems* if a soil venting system is installed or planned for the site. Additional information may also be necessary on a site specific basis.

4.0 Design and Installation of an Air Sparging System.

An in situ air sparging system consists of a number of components which are described in this section, beginning with a discussion of well placement and design. The discussion of design parameters includes well design, manifolds and blowers. Subsection 4.5 discusses other equipment that may or may not be used at sites, and the section concludes with a discussion of the information that should be submitted to the DNR.

4.1 Well Placement.

The air sparging well's zone of influence may be estimated by measuring one or more of the following:

- the change in water table elevation (upwelling);
- the use of gas tracers;
- measuring the change in dissolved oxygen (saturated zone);
- oxygen levels (unsaturated zone); and
- measuring the change in contaminant concentrations (saturated and/or unsaturated zone).

  Note: The use of any tracers requires prior approval from the Bureau of Water Supply.

It is permissible to select a well placement configuration without scientifically determining a zone of influence at the site, provided that a relatively close well spacing is used. The department does not recommend a specific method to determine a zone of influence. Well spacing of 12 to 50 feet has generally been used, according to the literature. If well spacing is closer than 15 feet or farther than 30 feet, designers should include a justification in the work plan. Some designers use a grid pattern of sparging wells in the source area and other designers use a line of wells oriented perpendicular to the direction of groundwater flow. Some designers have used the same number of air sparging wells as air extraction wells in the soil venting system (if installed) and other designers use a significantly larger number of sparging wells than air extraction wells.

Under active air sparging, the lateral distribution of contaminants in the saturated zone may increase due to the convection currents discussed above in Subsection 2.1. Therefore, additional groundwater monitoring wells and air sparging wells may be necessary near the perimeter of the contaminated zone. If air sparging wells extend to the perimeter of the plume, groundwater extraction may not be necessary at some sites. If air sparging is only used in part of the plume, groundwater extraction will probably be necessary to capture any lateral migration that results from convection currents.

The system designer should use their professional judgement to space wells in a pattern that will effectively decontaminate the aquifer and capillary fringe at the site.

4.2 Well Design.

Figure 4-1 portrays a typical air sparging well design.

4.2.1 Drilling Methods and Soil Descriptions.

A hollow stem auger is the preferred drilling method, and the auger should be 4.25-inch inside diameter (or larger) for 2-inch diameter wells. The wells should be 2-inch diameter or larger so that conventional well development equipment can be used. Designers should justify using drilling methods other than hollow stem auger on a site-by-site basis in the work plan.

Continuous sampling by split spoon is recommended to characterize/verify the geologic conditions because the geological conditions must allow the air to rise to the water table. It is highly recommended that a hydrogeologist collect samples from above the seasonal, high water table to the base of the screened interval from a sufficient number of wells to verify the geologic characterization. A hydrogeologist as defined in NR 500.03 (64) or NR 600.03 (98) should describe the soil in detail. See Subsection 2.2.2 for soil description information.

4.2.2 Filter Pack.

Designers should select the filter pack for the well based on the average grain size of the geologic materials below the water table. Samples for grain size analysis should be tested prior to designing an air sparging system. A sieve analysis is usually sufficient for filter pack design (a hydrometer test is usually not needed).

The average grain size of the filter pack should be as close to the native soils as practical. Coarser materials should not be used for the filter pack, however, slightly finer-grained material may be used. If the filter pack's average grain size is larger than the native geologic materials, the filter pack may be more permeable than the native soil. While a highly permeable filter pack is an advantage in constructing wells for other uses (monitoring or extraction), a filter pack that has a significantly higher permeability than the surrounding formation will be a conduit for upward short circuiting of air in the depth interval between the bentonite seal and the top of the well screen. This reduces the lateral movement of air into the aquifer. If the filter pack is significantly smaller than the native soils, too much restriction to air flow results. Natural filter packs may be used in caving formations provided that the native materials do not have significant levels of fines that may accumulate within the well screens.

The filter pack should extend from the base of the well screen to a minimum of 1 to 2 feet above the screen.

4.2.3 Seals.

A bentonite seal that is 0.5 to 2 feet thick should be placed above the filter pack. The annular space seal (above the bentonite seal) should be constructed with either bentonite cement grout or bentonite. A tremie should be used to place grout when installing a seal below the water table. The surface seal should be constructed in a manner that complies with NR 141.

Designers should use a flush mount protective cover over the well, as described in NR 141 if the manifold is buried. If so, other fittings discussed in Subsections 4.2.5 and 4.3 can be installed under the manhole cover(s). If there is not enough physical space for these fittings under an NR 141-approved cover, a different air- and water-tight manhole can also be used.

4.2.4 Well Screen and Casing.

Air sparging transfers air through the well screen to the filter pack and then to the contaminated zone within the aquifer. Since the majority of the air flows out of the well screen near the top of the screen, designers should set the top of the well screen at the base of the contaminated groundwater plume under seasonal low conditions. At a minimum, the top of the screen should be set 5 feet below the seasonal low static water table. If different criteria are proposed for setting the screen depth, designers should include a justification in the workplan.

The pressure that is needed to inject air into the aquifer is higher than the pressure that is required to depress the static water level to the top of the screen. Since a number of wells are manifolded together on a common header, all wells on a manifold are essentially operated at an equal pressure. If the top of a well screen in one well within a system is installed closer to the water table than the other wells, most and possibly all of the air will pass through this shallower well. This happens because less pressure is needed to inject air to the top of the screen in that well. Designers may use throttle or solenoid valves to equalize air flow to the wells, as an alternative.

At sites where groundwater will not be extracted, it is recommended that designers estimate the exact depth at which each well will be installed by:

- drawing an accurate water table map;
- surveying the elevations of proposed air sparging well locations; and
- calculating the estimated depth of the water table for each well to determine the screened interval.

If groundwater is extracted, a cone of depression significantly changes the shape of the water table. Other devices such as solenoid valves (See Subsection 4.3) may be needed to compensate for varying screen depths caused by the drawdown.

Sites with seasonal variations in groundwater flow direction may also adversely impact the system design.

> Example: A system that is designed for a site with natural groundwater flow toward the southwest. This site has higher water levels on the northeastern side of the site than the southwestern portion of the site. Later, the gradient shifts to a natural groundwater flow direction towards the southeast. The higher groundwater elevation will then be located in the northwest portion of the site.
>
> In this situation, the increase in groundwater elevation on the western side of the site increases the pressure requirements in air sparging wells on the western part of the site relative to the eastern part of the site. If all wells are on a single common manifold, then the western wells will not inject as much air as the eastern wells.
>
> In this case, the western side of the site receives less air (or possibly no air) from the air sparging wells, reducing overall system effectiveness. The use of throttle valves or solenoid valves may alleviate this situation (See Subsection 4.3).

The slot size should be appropriate to the filter pack size; filter pack sizing is discussed in Subsection 4.2.2. Since air readily passes through well screens, a small slot size usually is sufficient and underestimating the slot size (by a small margin) — relative to the filter pack — is usually acceptable.

A relatively short length of screen for a well, such as 2 to 5 feet is sufficient; some designers have proposed a 1-foot screen length. The well screen typically is a slotted pipe constructed of PVC or CPVC. Generally, the screen is flush threaded with schedule 40 or 80 pipe. A bottom plug is necessary. Designers should not use glued couplings and bottom plugs because they may adversely affect any groundwater samples from the wells.

In most cases, designers should use 2-inch well materials. If designers plan to use packers in the well at a later date to physically block off portions of a screen, other screen diameters (such as 4-inch) may also be used. In general, the screen diameter should not be smaller than 2 inches, because it is difficult to develop smaller diameter wells. The well casing and pipe schedule should be constructed of the same materials as the well screen. Drillers should install "O" rings or other seals and wrench all threaded casing joints tight to limit air leakage from the joints.

During well installation, the depth — from the top of casing or standpipe to the top of the screened interval — should be measured to 0.1 foot of accuracy.

4.2.5 Wellhead.

Designers should connect the wellhead to the manifold with a tee, which allows a threaded top cap to be attached. This configuration allows access to the well for bailers or water level measuring probes.

During the system installation, if the length of the well casing (or standpipe) is changed while connecting the well to the manifold, the change in elevation at the top of each well should be measured to 0.1 foot. Designers should adjust the well construction records to reflect any changes in the elevation at the top of the casing. The original casing measurement for each well is discussed in Subsection 4.2.4.

Wells should be surveyed to determine elevation if they are used for collecting groundwater samples or preparing a piezometric surface map (otherwise surveying for elevation is not necessary).

4.2.6 Development.

All wells should be developed to NR 141 standards to minimize fines that may accumulate in the screen. Water produced by well development should be handled in accordance with the DNR guidance on investigative wastes.

4.3 Manifold, Valves, and Instrumentation.

The manifold is typically buried underground; however, if land use and traffic patterns allow, the manifold may be installed above ground. If the manifold is buried, it may be installed at or below the frost level, or it may be installed just below the ground surface. If it is within the frost zone, it may need to be protected from frost with insulation and/or heat tape.

The manifold can be 2-inch diameter or larger and constructed of steel, PVC or CPVC. Other diameters and materials are also acceptable. Designers should not use PVC if heat tape is used; instead, they should use CPVC or other materials. PVC or CPVC may not withstand the pressure at elevated temperatures. See Subsection 4.4 for a discussion of the temperature increase in compressed air.

Unglued slip-fit fittings should not be used because the pressure may cause the fittings to loosen. See Subsection 5.2 for a discussion about volatiles in glues that may be used on glued fittings.

If a buried manifold constructed of plastic pipe is used, designers should install a steel wire or some other material that can be detected by a metal detector above the manifold piping. This provides a means of determining the exact location of the manifold with a metal detector. Note: This is unnecessary at sites where reinforced concrete is used, since the metal detector will only detect the rebar.

Marley (1992) recommends that designers install a check valve between each well and the manifold. This prevents the temporary high pressure in the screened interval of the aquifer from forcing air and water back into the manifold system from the well after the system is shut off.

Designers should install an adjustable throttle valve for each well. This allows the well to be isolated from the system, or to be adjusted for air flow rate. If the manifold is below grade and flush mount well covers are used, the valve between the manifold and the well can be located inside the well covers.

It may be necessary to throttle air flow rates to different wells for optimal operation. However, throttling air flow increases the requirements for blower capacity and restricting flow increases electrical requirements. Since throttling air flow to optimize system performance is inefficient — from an energy and equipment standpoint — the system should be designed precisely and only using throttling for system optimization. It is not appropriate to use throttling to compensate for an inadequate system design.

A port that can be used to temporarily attach a flow meter for each well is recommended. See Subsection 3.2 for a discussion of flow meters and Subsection 4.4 for a discussion of flow rates. If designers plan to adjust air flow to each well with the throttle valve, a means to temporarily attach a flow meter is absolutely necessary. Otherwise, it is impossible to know how to set the valve. If a flow meter is temporarily attached, it should not significantly change the air flow characteristics. For example: rotameters have significant flow restriction and should not be used temporarily on a permanent system; however, they may work well in pilot testing because they are used during the entire test.

Designers should install a port that allows temporary attachment of a pressure gauge and thermometer to the well, well cap, or manifold near each well to monitor the air injection pressure and air temperature at the well.

If a check valve is not installed on each well, designers should locate a single check valve between the manifold and the flow instrumentation described in the next paragraph.

A permanent pressure gauge, thermometer, and flow meter should be installed between the manifold system and the manual pressure relief valve (described in the next paragraph) to measure total system flow, temperature, and pressure. Designers should follow manufacturers recommendations for length of unobstructed flow — both upstream and downstream of the flow meter.

A manual pressure relief valve should be installed immediately after the air compressor outlet. This valve exhausts excess air from the manifold to either the atmosphere or the air compressor air inlet. A silencer may be needed if the valve exhausts to the atmosphere, but an exhaust silencer is unnecessary if the outlet is plumbed into the blower inlet.

An automatic pressure relief valve may be installed to prevent excessive pressure from damaging the manifold or fracturing the aquifer in the event of a system blockage (See Subsection 4.4).

Solenoid valves may be used on the wells to individually activate and deactivate different wells. When using solenoid valves, each well (or part of the well system) receives all of the air produced by the air compressor system for the period of time that the solenoid valve is open to that well(s). Thus, when operating only a single well — or only a few wells — at a time, solenoid valves reduce the possibility that a single well in the system will transmit an unusually large or small amount of air. If solenoid valves are used, the AVERAGE air flow rate over time should be within the 0.5 to 20 scfm range that is recommended in Subsection 4.4. See Subsection 4.5 for a discussion of control panels.

If solenoid valves or timers are used, cycling the wells may cause surging in the wells, similar to surging during well development. Surging may cause silt to buildup in the wells, requiring periodic jetting of the wells to remove the fines. Buildup of fines in the wells may be reduced by placing a check valve on each well to reduce backflow.

Solenoid and check valves may significantly restrict air flow. The pressure drop across solenoid and check valves (if used) should be evaluated as part of the design.

4.4 Air Compressor Selection.

There is no database or calculations to determine the air requirements for air sparging to remediate a site. The average air flow rate should be in the range of 0.5 to 20 scfm per well. If an average air flow rate proposal is outside of this range, the proposed flow rate should be justified in the work plan. Marley (1992) indicates that typical air flow rates are 3 to 10 scfm per sparge point.

Designers should avoid excessive pressures that could cause equipment failures and/or the creation of secondary permeability in the aquifer (See Subsection 2.1). There may be situations where pneumatic fracturing is desired, but HIGH PRESSURE TECHNIQUES THAT MAY FRACTURE THE AQUIFER SHOULD NOT BE USED WITHOUT JUSTIFICATION IN THE WORK PLAN AND PRIOR APPROVAL FROM THE DEPARTMENT.

Example: To estimate the maximum pressure that can safely be used without creating secondary permeability, assume that the pressure must not exceed the weight of the soil column above the screen.

Assumptions:

- soil particle density of 2.7,
- water table depth at 18 feet,
- sparging system screened interval from 30 to 35 feet, and
- porosity of 30 percent or 0.3.

To estimate the overlying pressure exerted by the weight of the soil column:

Weight of soil $= 30\ ft * 2.7 * (1-0.3) * 62.4\ lbs/ft^3$

$= 3{,}538$ *pounds per* ft^2

Weight of water $= (30-18)\ ft * 0.3 * 62.4\ lbs/ft^3$

$= 224$ *pounds per* ft^2

Total $= 3{,}538 + 224 = 3{,}762\ lbs/ft^2$

$= 26$ *psig at 30 feet of depth (the top of screen).*

In this case, injection pressures higher than 26 psi could cause secondary permeability channels to develop. This example is based on simplistic assumptions and designers should evaluate additional geotechnical information if it is available.

Using pilot test data, designers should calculate the pressure that is necessary to achieve the desired flow rate under both seasonal high and low water table conditions. Professional judgement is necessary to determine the design pressure and flow rates per sparging point. If an air flow rate of 0.5 scfm cannot be maintained at the maximum pressure, the soil permeability may be too low and in situ air sparging may not be appropriate for the site.

The air compressor needs to produce sufficient pressure to depress the water level in all wells below the top of the screen. The pressure needed to counteract the static water level in the wells can be significant during seasons of high water levels. During seasons of low water levels — when the top of the screen is closer to the water table — the pressure is much lower and the air compressor can inject much more air to the system. The air compressor should not be capable of injecting too much air flow relative to the soil venting system flow rate (See Subsection 1.2.1).

Since ambient air is used in an air sparging system, non-explosion proof equipment may be used if the air compressor and associated wiring is in a safe location. Explosion-proof equipment may be used as a safety precaution. It is the responsibility of the system designer to verify the safety of non-explosion proof equipment. Local electrical inspectors may also require explosion-proof equipment on a site-specific basis.

System designers should only use air compressors that are rated for continuous duty. Common air compressor types include:

- Reciprocating Air Compressors. Reciprocating air compressors should only be used when high pressure is required and a low-flow rate is acceptable. Only oil-less air compressors are acceptable because of the potential to inject oils into the aquifer if a seal (piston ring) fails. Since these air compressors may produce sufficient pressure to burst PVC and CPVC pipe and fittings, designers should install an automatic pressure relief valve on the air compressor outlet.

- Rotary Lobe Blowers. Rotary lobe blowers are positive pressure blowers capable of pressurizing air up to 15 pounds per square inch. Blowers may have an oil-filled gear case, but may not use any other lubricants or fluids that could enter the air stream and reach the groundwater.

- Regenerative Blowers. Regenerative blowers are relatively simple and maintenance free compared to the other blowers. Because of their low pressure capability, regenerative blowers can only be used at sites that can be operated at relatively low pressures. In most cases, it is likely that a multi-stage blower will be needed for higher pressure capability.

Designers may use other compressor types, such as a rotary screw compressor. If designers use an alternative compressor that could inject oil, a filter must be used to remove the oil. Designers need preapproval from the DNR Bureau of Water Supply when using alternative compressors.

Designers should install an air filter that prevents particulate matter from damaging the air compressor. A silencer on the air inlet may also be desired.

The air inlet should be installed in a contaminant free environment. The air inlet should be located outside of the building if the air compressor is installed inside of a building that may have airborne contaminants — such as a service garage. If the air inlet is located near the stack of a soil venting system, designers should use a minimum of 10 feet of vertical separation. If ambient outside air is used, the system should only be operated when the injected air temperature (measured at the wellhead) is equal to or greater than the natural groundwater temperature.

As part of the design, the system designer should calculate the air compressor exhaust temperature based on manufacturer's data. CPVC, steel or other materials should be used instead of PVC manifold materials if the blower exhaust temperature is higher than 140 degrees fahrenheit. If the blower exhaust temperature is higher than 200 degrees fahrenheit, either a heat exchanger or pipe materials other than CPVC may be necessary. If pressures higher than 15 psig are anticipated, evaluate manifold materials for strength at anticipated operational temperatures and pressures.

If the compressor has a receiver (air tank), an automatic water trap is also recommended to drain condensate from the receiver. Note: Condensate from a "clean" air tank is not considered an investigative waste.

4.5 Other Devices.

The DNR Bureau of Water Supply needs to approve any other devices, including heaters, that have any potential to introduce contaminants into the injected air stream. Other devices that may be used include the following:

<u>Control Panels.</u> Solenoid valves, if used, are controlled by a panel with a timing device (See Subsection 4.3) to sequence each valve for a period of minutes.

<u>Thermal or Pressure Sensor.</u> A sensor located at the blower exhaust may be used for automatic shutdown if the pressure and/or temperature exceeds design criteria.

<u>Timers.</u> A timer may be needed to limit initial air emissions (See Subsection 5.1).

<u>Heaters.</u> Heaters may be used in some situations to warm the injected air. Heaters that may inject air that is deficient in oxygen should not be used at sites with aerobically degradable contaminants. In most cases, the heat added during compression should add enough heat to maintain the temperature above the natural groundwater temperature, however, systems that operate at low pressure in winter may require additional heat. Also, additional heat may be necessary in winter if long piping runs are exposed to subfreezing temperatures.

<u>Oxygen Generators.</u> Some sites may use oxygen injection instead of or in addition to air injection. Oxygen generators must receive prior approval from the Bureau of Water Supply. Levels of oxygen should not be excessive at sites where the change in groundwater redox conditions could be detrimental, such as sites with high levels of dissolved iron.

Pure oxygen is a highly reactive substance. If pure oxygen or elevated levels of oxygen (relative to atmospheric oxygen concentration) are used, ALL MECHANICAL COMPONENTS THAT ARE IN DIRECT CONTACT WITH THE OXYGEN SHOULD BE APPROVED BY THE MANUFACTURER FOR USE IN PRESSURIZED OXYGEN-RICH ENVIRONMENTS. Components that are not designed for use in pure oxygen may cause a fire and/or catastrophic failures of pressurized lines, pressure vessels, valves, and fittings.

4.6 Monitoring Plan.

System operators should monitor two or more groundwater monitoring wells downgradient from the farthest downgradient air sparging well on a regular basis for the parameters appropriate to the contamination at the site. If the contaminants aerobically degrade, it is also appropriate to monitor dissolved oxygen in those monitoring wells.

During startup, samples need to be collected from groundwater monitoring wells to determine if there are any changes in the groundwater flow patterns that are caused by convection currents. This includes monitoring side and upgradient wells to determine if contamination is forced outside the zone of influence. If after three months, contaminant migration outside the zone of influence does not exist, sampling frequency in side and upgradient wells may be reduced or eliminated at most sites.

The DNR project manager may require additional monitoring points, frequency, and parameters.

If a soil venting system is also installed, refer to the *Guidance on Design, Installation and Operation of Soil Venting Systems* for monitoring requirements for the soil venting system.

4.7 Air Sparging System Design Report.

An air sparging system design may be included in a comprehensive report with the results of an investigation, or it may be submitted separately. The design report of a sparging system should include the following:

<u>Discussion.</u>

- Briefly discuss the geologic and hydrogeologic conditions at the site and an include an estimate of the natural migration rate of the groundwater. If any stratification is present at the site, include a detailed discussion of how the air flow patterns are affected,

- Discuss the anticipated changes of the groundwater flow patterns that may be caused by convection currents and ways the system design will limit/prevent migration of contaminants outside of the zone of influence.

- Include a general description of the system: number of wells, air flow rate and pressure requirements, etc.

- Describe the reasoning used to establish well spacing and the well pattern (grid or line).

- Include results of any pilot tests that were conducted. Discuss the air flow rates that were injected and extracted during the pilot test and how the contaminant concentrations in the unsaturated zone changed with differing air injection rates.

- Include a proposed monitoring plan for monitoring wells, including sampling frequency and parameters. If the wells have not yet been installed, discuss the proposed locations of the wells.

- Include a design of the sparging wells. Provide details on the following:

  - screen length and diameter;
  - slot size;
  - depths and specification of the filter pack and seals;
  - depth of the screens relative to the water table;
  - bore hole diameter; and
  - the drilling method.

- Include a manifold design with the following information:

  - pipe type;
  - diameter;
  - location of valves;
  - a description of instrumentation for measuring air flow rate, vacuum and temperature; and
  - the depth of the manifold, if buried.

- Include air compressor specifications with total anticipated air flow rate and pressure levels. Also discuss the ratio of extracted air to injected air if a soil venting system is installed/proposed for the site.

- Include details of any other remediation systems that are planned for the site.

- If free product exists at the site, designers should describe what measures they will take to avoid pushing free product into other areas by upwelling.

- If a soil venting system is not proposed for the site, include a justification and address all of the constraints outlined in Subsection 1.3.1 of this guidance.

Figures.

- Include a map of proposed air sparging well locations drawn to scale. The map should include the following:
  - locations of proposed and existing sparging wells;
  - the manifold location;
  - location of air compressor and other equipment;
  - location of the air inlet to the air compressor;
  - suspected and/or known source location(s) (if differing contaminant types are present at a site, identify the contaminant types for each source area);
  - zone of soil contamination;
  - zone of groundwater contamination;
  - scale, north arrow, title block, site name, and key or legend; and
  - any other pertinent site information.
- A current water table map.
- Geologic cross section(s).
- A map indicating the proposed monitoring locations for determining sparging effectiveness. (This map can be combined with the water table map into one figure.)
- Process flow diagram indicating the piping layout, instrumentation and other key components.

Tables.

- Table of water levels/elevations in monitoring wells.
- Table of anticipated air sparging well screen depths and static water levels.

Appendices.

- Calculations for determining the well placement, if any.
- Designers should include engineering calculations used to select the air compressor. Include the manufacturer and model of the air compressor, the performance curve that is provided from the manufacturer, total anticipated air flow rate, pressure levels, anticipated air compressor exhaust temperature, and type and size of air compressor. If the air compressor is belt driven, the rpm of the blower should be listed if that data is used for calculating the flow rate. If a pilot test was performed, include the graph indicating the flow and pressure relationships observed during the pilot test.
- Grain size analysis of the soils.
- Calculations determining the hydraulic conductivity and natural groundwater migration rate.
- Detailed field procedures for monitoring dissolved oxygen (if measured).

All information listed in Subsection 4.10 in the *Guidance on Design, Installation and Operation of Soil Venting Systems* should also be included if a soil venting system is installed or planned for the site. Additional information may also be necessary on a site-specific basis.

5.0 Operating an Air Sparging System.

5.1 Overview.

Operation of an air sparging system requires ongoing monitoring and system adjustment to maximize performance. Efficient and successful operation of the system requires a continuous effort to ensure the system operates efficiently. It is the responsibility of the consultant to operate the system in an effective manner.

If consultants find a more efficient/ effective method to operate the system, they should evaluate any changes to the system on an economic basis. If a system is not operated properly, a contaminated groundwater plume may migrate from the site.

If the emissions from the combined vapor extraction and sparging system are initially expected to exceed allowable air standards, operators may need to cycle the sparging system (but not the negative pressure vapor extraction system) by operating it for a few minutes each hour on a timing device. Refer to the discussion of cycling and potential silt buildup in the wells in Subsection 4.3. Subsection 3.2 contains information on how to calculate the expected emissions increase, which is attributable to air injection upon start-up. After emissions drop, the sparging system may be operated continuously.

An alternative to cycling the sparging system is to control air emissions on the soil venting system with a treatment device.

During the first few months of operation, it is necessary to monitor the upgradient, side-gradient, and downgradient monitoring wells to verify that convection currents are not causing lateral migration of contaminants outside the zone of influence.

Operators should use downgradient groundwater monitoring to verify the system's effectiveness. If downgradient monitoring indicates that a system is not working, the designer should assess the system and plan to correct any problems. The department may require additional modifications.

5.2 Start-up Testing.

Prior to start-up, volatiles should be purged from the manifold system if any chemical adhesives were used in constructing the system. To purge all volatiles from the system prior to injecting air into the aquifer, operators should run the air compressor for a minimum of 10 minutes — and up to two hours — with all well valves open and all well caps and covers removed. All air exhaust from the manifold system will then exhaust from the wellheads and will not be injected into the aquifer. After the initial purge is complete, operators should replace the caps and well covers.

After an air sparging system is constructed, operators should conduct on-site testing of the system using the following guidelines:

- If solenoid valves are not used to equalize flow to each well, operators should evaluate each well for flow and pressure characteristics by using a flow meter at each well. Throttle valves should then be used to equalize flow to each well.

- Upon start-up, an air sparging system can produce significant volatilization of VOCs. The department highly recommends using field instruments at start-up to evaluate air emissions from the soil venting system.

- If there is any bubbling in piezometers at the site, operators should install air-tight caps on these wells. If these wells are uncapped, they could be a conduit for air flow to short circuit through the well instead of through the contaminated aquifer.

- Take total pressure and flow measurements after the system stabilizes and measure the pressure or vacuum at gas probes and water table wells to evaluate different parts of the site for subsurface air pressure/vacuum.

SYSTEM OPERATORS SHOULD REEVALUATE CONTINUED OPERATION OF THE SPARGING SYSTEM FOR SAFETY REASONS IF ANY POSITIVE SUBSURFACE AIR PRESSURE READINGS AND/OR HIGH LEVELS OF VAPOR PHASE CONTAMINANTS ARE MEASURED IN GAS PROBES ADJACENT TO BUILDINGS OR OTHER STRUCTURES THAT MAY ACCUMULATE DANGEROUS VAPORS. OPERATORS SHOULD DISCONTINUE OPERATION OF THE AIR SPARGING SYSTEM IF CONDITIONS ARE UNSAFE. It may be necessary to turn off selected sparging wells to reduce subsurface pressure in some cases.

If some of the wells require more air pressure than the operating pressure provided by the air compressor — and therefore do not transmit any air — operators should evaluate replacing the wells or repairing the system.

5.3 As-built Submittal.

After completing the on-site tests described above, operators should include the system as-built information in a report. Because most of the information is included in the design report, a separate submittal is usually not necessary. In most cases, the as-built information can be included in the first progress report after start-up (See Subsection 5.4). The as-built submittal should include the following information:

- Results of on site testing to verify that each well transmits approximately the same amount of air.

- Any deviations from the specifications in the design report.

- A map of actual well locations drawn to scale, including:

  - locations of existing sparging wells;
  - the manifold, instrumentation, and sample port locations;
  - location of air compressor and other equipment;
  - suspected and/or known source location(s) (if differing contaminant types are present at a site, identify the contaminant type at each location);
  - zone of soil contamination;
  - zone of groundwater contamination;
  - scale, north arrow, title block, site name, and key or legend; and
  - any other pertinent site information.

- Table of air sparging well screen depths and static water levels prior to start-up.

- Well construction diagrams.

- Boring logs and any other information required by NR 141.

- Any other pertinent information.

5.4 Progress Reporting.

Consultants should sequentially number progress reports, starting with the first report after the remediation system start-up. In most cases, it is sufficient to include only one or two pages of text in a letter format with supplementary tables, graphs and a site map. The progress reports should include the following information:

- A brief discussion of the remediation system's progress that includes the following information:

  - Contaminant extraction total to date in pounds or gallons of contaminant removed;
  - System operational details, periods of shut down,

  equipment malfunctions, etc.;
  - Overall evaluation of the effectiveness of the system;
  - Changes and those effects on the sparging system, if the water table elevation has changed significantly from the position that the system was originally designed; and
  - Recommendations and justifications for future activities, if appropriate.

- A site map that indicates the location of wells, etc. The well location map from the as-built submittal is sufficient.

- A water table map from the most recent round of water levels. This map can be combined with the above-mentioned site map.

- Tables that include data throughout the project are useful to establish trends. Tables should include the following information:

  - Field data and flow rate measurements;
  - Water levels/elevations.
  - Analytical data summarized from laboratory reports.

- Laboratory reports.

- A discussion of sampling procedures, analytical procedures, etc. is not required, but a reference to the report that lists the procedures should be included.

- If a soil venting system is operational, the information included in Subsection 5.3 in the *Guidance on Design, Installation and Operation of Soil Venting Systems.*

- Any other pertinent information or data.

Operators should submit progress reports each month for the first three months of the system's operation and quarterly thereafter, unless otherwise instructed by the department. The DNR project manager has the authority to add additional monitoring and submittal requirements to the above list based upon specific site conditions.

5.5 Project Close Out.

Consultants should follow the procedures in Chapter 10 of the *Guidance for Conducting Environmental Response Actions* when closing out a site. Note: At the time this Guidance was prepared, Chapter 10 was not yet complete.

After gaining approval to close out a site, all wells should be abandoned within 60 days (after they are no longer used), according to NR 141. If a sparging well is used for groundwater sampling as part of long-term monitoring, that well is considered to be in use and does not require abandonment until long-term monitoring is concluded.

6.0 References.

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Wisconsin Administrative Code NR 141, Groundwater Monitoring Well Requirements.

Wisconsin Administrative Code NR 419, Control of Organic Compound Emissions.

Wisconsin Administrative Code NR 445, Control of Hazardous Pollutants.

Wisconsin DNR - Guidance on Design, Installation and Operation of Soil Venting Systems.

Wisconsin DNR - Guidance on Design, Installation and Operation of Ground Water Extraction and Product Recovery Systems.

CORRESPONDENCE/MEMORANDUM

DATE: August 14, 1991 FILE REF: 4440

TO: District LUST Staff

FROM: Robert Krill, WS/2
Paul Didier, SW/3

SUBJECT: Policy on Air Sparging Wells for Groundwater Remediation.

Air sparging wells are used to inject compressed air into a shallow part of the aquifer. The purpose of using compressed air injected into wells is to air strip VOCs from the groundwater and oxygenate the water which will promote biodegradation of aerobically biodegradable compounds. A summary of pertinent regulations is as follows:

- Section NR 112.05 administrative code - addresses injection wells. .... underground placement of any substance as defined in s. 160.01 (8), Stats., is prohibited.

- Section 160.01(8) Wi statutes - defines substances to include .... any solid, liquid, ... or gaseous material .... (that) ..... may decrease the quality of groundwater.

Since the air sparging wells are intended to improve groundwater quality and will only be used to inject air in groundwater that has already been impacted by contamination, they are considered beneficial.

To assure that the air sparging system does not introduce any "substances" into the groundwater, an oil-less air compressor, oil-less rotary lobe blower, or oil-less regenerative blower must be used. (Note: Rotary lobe blowers that use lubricants in a gear case are acceptable.) If any other blowers are proposed for use, consultation with the Bureau of Water Supply is always necessary.

If an air pump is used that meets the above criteria, and if the air pump inlet is in an area free of atmospheric contaminants, and if no other devices are present that may contaminate the injected air stream, approval from Water Supply is not necessary.

The Bureau of Water Supply reports injection wells to the EPA, for this reason Rich Roth must be copied on approval letters (including old projects that are already approved) for air sparging projects, his address is;

Richard Roth
Bureau of Water Supply, WS/2
P.O. Box 7921
Madison, WI 53703

The Bureau of Water Supply will allow the LUST program to approve air sparging projects on their behalf in accordance with the above requirements.